An Interaction Framework for Level-of-Abstraction Visualization of 3D Geovirtual Environments

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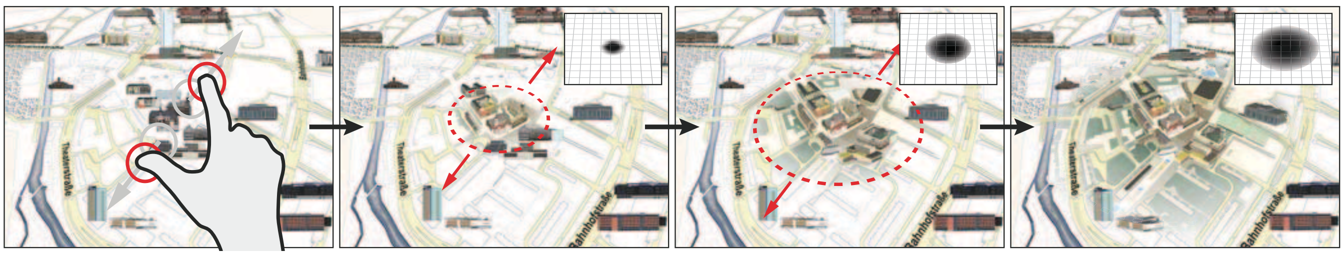

Figure 1: Touch-based interaction using our framework with the *pinch-to-zoom* metaphor to parameterize the level of abstraction of 3D geospatial objects in a region of interest for focus+context visualization.

ABSTRACT

3D geovirtual environments constitute effective media for the analysis and communication of complex geospatial data. Today, these environments are often visualized using static graphical variants (e.g., 2D maps, 3D photorealistic) from which a user is able to choose from. To serve the different interests of users in specific information, however, the spatial and thematic granularity at which model contents are represented (i.e., level of abstraction) should be dynamically adapted to the user's context, which requires specialized interaction techniques for parameterization. In this work, we present a framework that enables interaction interfaces to parameterize the level-of-abstraction visualization according to spatial, semantic, and thematic data. The framework is implemented in a visualization system that provides image-based rendering techniques for context-aware abstraction and highlighting. Using touch and natural language interfaces, we demonstrate its versatile application to geospatial tasks, including exploration, navigation, and orientation.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Interaction styles, Input devices and strategies*; I.4.3 [**Computer Graphics**]: Image Processing and Computer Vision—*Enhancement*—*Filtering*

General Terms

Algorithms, Design, Human Factors

MapInteract'14, November 04-07 2014, Dallas/Fort Worth, TX, USA

ACM 978-1-4503-3141-8/14/11…$15.00 http://dx.doi.org/10.1145/2677068.2677072

Keywords

interaction, level of abstraction, 3D virtual environments, focus+context visualization, interactive map design

1. INTRODUCTION

3D geovirtual environments (3D GeoVEs), such as virtual 3D city and landscape models, constitute effective media for the analysis and communication of complex geospatial data in manifold applications, such as city planning, navigation, and disaster management. General-purpose systems like Google Earth™ or Microsoft Bing Maps™ typically represent these environments with a pre-defined set of graphical variants, which is often constituted by 2D/2.5D map-like representations (e.g., for navigation), and 3D photorealistic representations (e.g., for exploration). According to a user's background, task, and perspective view, however, often too much irrelevant (cluttered) or too few information is visualized [32], and thus not a meaningful map design is provided [19]. Changing different graphical variants is a common approach to address this concern, but memorizing these may affect a user's visual attention and performance significantly [22, 34].

Another promising approach is to select the spatial and thematic granularity at which model contents are represented (i.e., level of abstraction, LoA) according to a user's interest in local regions (Figure 1), or according to thematic and semantic information. Previous works showed how interactive LoA visualization of 3D geovirtual environments can be technically achieved (e.g., using view metrics [31]). Yet a fundamental problem lies in the way on how a user-defined parameterization of the LoA can be intuitively performed via interaction devices and techniques (e.g., to parameterize magic lenses [35]), which remains to be explored.

In this paper, we present a framework for interaction interfaces to parameterize the level-of-abstraction visualiza-

Figure 2: Comparison between static representations of a 3D geovirtual environment in Google Maps™(left, middle) and our approach that is able to interactively select and combine levels of abstraction (right).

tion of 3D geovirtual environments. We base our framework on image-based rendering techniques using deferred shading of modern GPU architectures to enable smooth transitions between focus and context regions with different graphical representations [31] (Figure 1/2). In particular, geometry buffers (G-buffers) [28] and distance transforms [6] are used to enable a flexible mapping of user interaction to geospatial properties in real-time. We further provide use cases for our framework using touch-based and natural language interaction (e.g., via textual descriptions) to parameterize a context-aware abstraction and highlighting, i.e., semantic depth-of-field [17], image filtering in texture space [30] to direct a user's pre-attentive cognition [29], and cartographic visualization techniques [31]. In addition, interactively selecting the LoA is able to significantly reduce the data transfer in client-server environments, and improve overall rendering performance because only relevant data is processed.

The remainder of this paper is structured as follows. Section 2 reviews related work. Section 3 gives a technical background and states challenges on interactive LoA visualization. Section 4 presents our framework for parameterizing the LoA visualization of 3D geovirtual environments, which is exemplified for concrete use cases in Section 5. Finally, Section 6 concludes this paper.

2. RELATED WORK

Our work is related to focus+context interfaces and visualization, and interaction techniques designed to parameterize a context-aware abstraction within 3D virtual environments.

2.1 Focus+Context Interfaces & Visualization

Focus+context describes the concept to visually distinguish between important or relevant information from closely related information [7]. Focus+context visualization conforms with the visual information-seeking mantra [32] by enabling users to interactively change the visual representation of data for points and regions of interest [1], and to solve the problem of over-cluttered visual representations. Many additional interface schemes exist to allow users to attain both focused and contextual views of their information spaces, i.e., detail+overview, zooming, and cue techniques [4]. Because the efficiency of these schemes highly depends on a user's task, our work explores a combination of these interfaces and how they can be coupled with a level-of-abstraction visualization via explicit and implicit view metrics (e.g., region interest, view distance).

Interactive lenses have become established means to facilitate the exploration of large data sets, and are quite versatile in their parameterization [35]. First approaches have been provided via the *magic lense* metaphor [2], and extended for 3D spaces [38]. The concept has also been explored for illustrative visualization [20] and 3D geovirtual environments [27] (e.g., for navigation, landscaping, urban city planning) to reveal information that is hidden in high-dimensional data sets. Typically, the concepts are combined with context-based geometric or graphical style variances to direct a user's pre-attentive cognition [29]. A common method is to parameterize image filters according to view metrics (e.g., view distance) or regions of interest to select and seamlessly combine different LoA representations of 3D scene contents [31] or map contents (e.g., route visualization [13]), or to combine different generalized geometric representations [37]. In our work, we demonstrate how user interaction can directly parameterize these kind of visualization techniques using image-based shading on the GPU. In particular, we provide use cases of the semantic depth-of-field effect [17, 36] for information highlighting and abstraction.

2.2 Interaction in 3D Virtual Environments

Many systems use a classical mouse/keyboard setup with an optional graphical user interface to inspect objects and parameterize the visualization of 3D virtual environments [11]. Direct manipulation is typically coupled with ray casting to determine intersections of a pointing device with the visualized output (e.g., to specify regions of interest [35]). Due to the increasing availability of ubiquitous devices, such as smartphones and tablets, visualization systems also increasingly make use of the opportunities of (multi-)touch interaction [18]. Evaluations showed that these interfaces provide a quite natural direct-touch interaction within virtual environments [26], and may outperform mouse input for specific tasks in terms of completion times [15]. However, touch user interfaces also adhere to certain challenges, such as the intuitive mapping from 2D input to 3D manipulations [10, 14]. Our work provides a generic interface for user interaction (e.g., mouse, touch gestures, textual input) to parameterize the visual representation on a spatial, thematic, and semantical basis, which is exemplified for virtual 3D city models, and exploration, navigation and analysis tasks. The mapping is performed interactively via image-based rendering, geometry buffers [28] and distance maps [6], and thus is extensible for arbitrary shading effects.

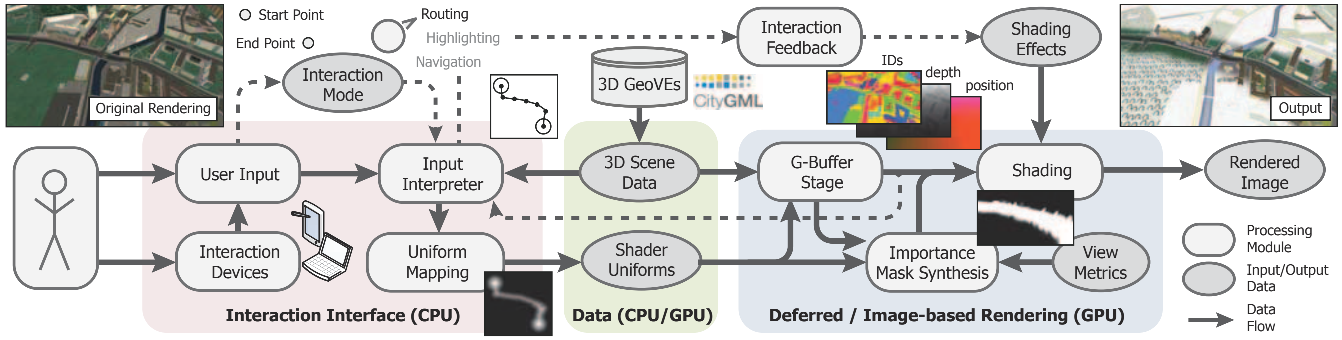

Figure 3: Overview of our framework, which is arranged in three components: an interaction interface, scene data and parameter processing, and rendering. The framework is subject for further discussion in Section 4.

3. BACKGROUND AND CHALLENGES

User involvement is a critical design aspect for 3D geovirtual environments. A good design presents as much information as needed for focus and as little as required for context [25]. Four major interface schemes have been identified for focused and contextual views [4]: zooming, focus+context, overview+detail, and cue techniques. Using these schemes with parameterized graphical variants of 3D geovirtual environments, however, remains a challenging task, because these environments are often inherently complex with respect to geometry, appearance, and thematic information. Here, a major goal is to provide a framework that seamlessly integrates into the real-time rendering pipeline, and is extensible for custom interaction devices and techniques.

The programmable pipeline of modern graphics hardware facilitates graphical variants to be selected and parameterized in a flexible way. A promising approach is deferred rendering, where geometry information is rendered in a G-buffer [28] and then used in a post-processing stage to perform image-based algorithms on visible fragments only. In particular, this method has been proven effective for non-photorealistic rendering techniques to implement how important or prioritized information is highlighted and cognitively processed in an application context [29]. General concepts that parameterize the deferred rendering pipeline according to user interaction have been proposed for highlighting [36] and LoA visualization [31, 30]. A generic interaction interface for these implementations, however, remains to be explored. Here, we identified two major challenges:

1. Rendering should be decoupled from concrete interaction interfaces, and instead be parameterized via high-level descriptions to facilitate an easy deployment of new interaction devices and techniques.

2. Interactive frame rates should be maintained to provide a responsive system to the user.

In the next Section, we show how the deferred rendering pipeline can be effectively parameterized using uniform buffers and textures as abstraction layer.

4. INTERACTION FRAMEWORK

An overview of our framework is shown in Figure 3. It is generic in its application and can be seamlessly integrated into existing visualization systems. The input data consist of 3D meshes with additional attributes (e.g., semantics) and textures for appearance and thematic information (e.g., using CityGML [16]). The main idea of our framework is to decouple the interaction interface from rendering, and instead use uniform buffers and textures for LoA parameterization. First, input via interaction devices and techniques is interpreted according to a pre-configured interaction mode, and mapped to a functional description to configure GPU resources (Section 4.1). The resources are then uploaded to GPU memory and evaluated in a deferred rendering stage to dynamically compute importance masks (Section 4.2). Multiple importance masks may be computed and blended to enable multi-variate highlighting and abstraction effects, and may be additionally parameterized according to view metrics for view-dependent LoA visualization. The framework provides presets of semantics-based shading for map-like representations, and image filtering techniques for focus+context visualization.

4.1 Interaction Interface

In the following, we define a generic workflow on how user interaction can be mapped to definitions of focus and context and their graphical representations via shading.

User Input, Interaction Devices and Interpreter

A concrete challenge for the design of an interaction interface is to strive for consistency while having the user in control of parameterization the visualization process [33]. Here, a key observation is that no constraints regarding the input device or technique should be made, i.e., to allow users to use the best direct interaction method for parameterizing a visualization system for a given task. Our main idea is to decouple the functional descriptions of focus and context from the concrete interaction device, e.g., so that mouse/keyboard, touch-based or implicit gaze-based interfaces [8] can be used equally to define a region of interest. Optionally, natural language input should be possible for automatic highlighting. Technically, the interaction interpreting is formulated as mapping the user-defined input to a high-level functional description for focus and context definition. To avoid redundant mappings, interaction modes are required for disambiguation, but should be made as concise as possible (e.g., using quasi-modes [24]). Exemplary mappings include object selection by textual lookup via natural language interfaces (e.g., line edit widgets), or via direct selection using *point-and-click* metaphors or tap

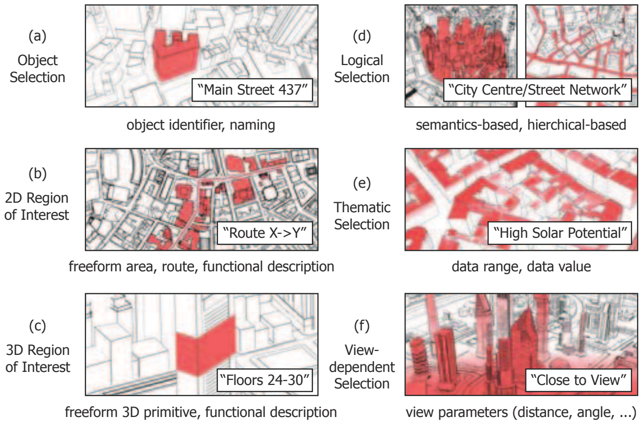

Figure 4: Types for focus definition and mapping of exemplary high-level descriptions into model space.

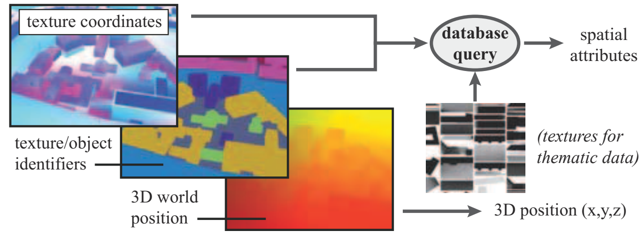

Figure 5: Using G-buffers to map texture coordinates, identifiers, and positions to spatial attributes.

gestures. Similarly, a circular region of interest can be defined via *pinch-to-zoom* metaphors (Figure 1) or sketching (e.g., shape strokes). Technically, the mapping to high-level descriptions can be realized using logical collections of 3D model data as input, enriched with descriptive information that is stored as attributes (e.g., encoded with CityGML [16]). These attributes are then used to map user-defined input from parameter space into model space. Dealing with 3D geovirtual environments, we distinguish between six categories for focus definition (Figure 4):

1. *Object selection*: The highlighting of single or groups of objects that serve as landmarks according to a user's context and interest.

2. *2D region of interest*: The highlighting of objects that are located close to, or within a 2D region of interest.

3. *3D region of interest*: The spatial highlighting of objects or components with additional constraints in height.

4. *Logical selection*: The selection of objects or components with respect to semantic constraints, such as feature type (e.g., street networks).

5. *Thematic selection*: The selection of objects or components with respect to thematic data, such as population or solar potential, and according to a range of interest.

6. *View-dependent selection*: The definition of regions of interest according to view-based metrics (e.g., viewing distance to virtual camera, or viewing inclination).

Direct interaction for these focus and context definitions should trigger immediate visual feedback to symbolize a correspondent mode, for which we provide specialized shading effects. For instance, using the *pinch-to-zoom* metaphor to define a circular region of interest (Figure 1) visualizes its boundaries as projected circular cues. From a cartographic point of view, choosing an adequate graphical representation of the focus and context definitions is task-dependent, for which we implemented a range of image-based filtering techniques [30] that are provided as presets a user can select from (Section 5).

In most interaction modes, a basic functionality is to map 2D input to 3D attributes via raycasting (e.g., for object selection [11]). It is typically performed using intersection tests with the 3D scene geometry, but may become too complex to be interactively performed. Instead, we use an image-based approach using the geometry buffer [28] of the rendered contents to query 3D scene attributes for the visible parts only. We observed that the world position, texture coordinates, and identifier information (i.e., objects, textures) synthesized in a G-buffer are sufficient to query arbitrary spatial information (Figure 5). For instance, texture identifiers and coordinates directly map into texture space for a fragment-based information lookup, whereas object identifiers can be mapped to any kind of object-specific attributes. Refer to Figure 3 for a route definition and how it maps to 3D virtual environments. In the following, we focus on direct interaction performed on the rendered image or task-oriented interaction via high-level descriptions.

Shader Uniform Mapping

High-level descriptions for focus regions are either mapped to GPU uniform buffers or textures. In the first case, parameters are directly evaluated on the GPU for shading. In the second case, we make use of the parallel-banding algorithm [3] to compute an exact distance transform in real-time. The synthesized distance maps are then used for projective texturing [9]. This approach enables image-based operations to be effectively implemented, such as fragment-based thresholding of the Euclidean distance between 3D objects to regions of interest (e.g., distance to a route or point of interest) for image blending and overlays. Refer to Figure 6 for exemplary results.

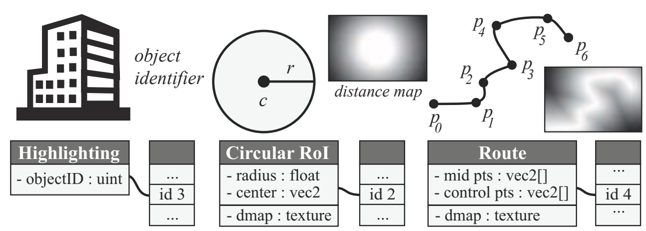

Figure 6: Exemplary mapping of focus definitions to shader uniforms and distance maps.

4.2 Rendering Interface

Deferred rendering with image-based shading is employed to maintain interactive frame rates. In addition, visual feedback is provided during interaction if appropriate (e.g., the boundary of a region of interest during definition, Figure 1).

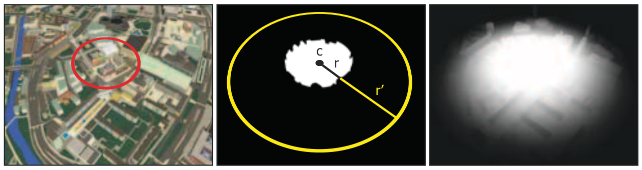

Figure 7: Exemplary synthesis of a smoothed importance mask for a user-defined region of interest.

Importance Mask Synthesis

The uniform parameters are evaluated using fragment shaders. For each definition type, an importance mask is synthesized that indicates whether a fragment should be shaded for focus or context (Figure 7). Blend functions are utilized for image composition [23] and enable smooth transitions between focus and context regions, but may also be configured to enable hard transitions (Figure 8), e.g., to avoid distorted color tones or emphasize regions of interest when using heterogeneous graphical representations for focus and context. All computed importance masks of a 3D scene are blended to enable multivariate effects (e.g., a route with a circular region of interest at the destination). Optionally, view metrics (e.g., distance of fragments to viewing position) are evaluated for view-dependent focus+context visualization [31].

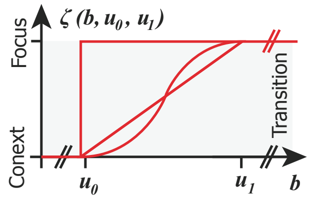

Figure 8: Exemplary transition functions.

Shading and Composition

We explored two shading procedures. First, explicit shading effects that are defined per model semantics. Previous work showed that this method facilitates visualization with map-like representations, i.e., using cartographic design principles [31] (refer to Figure 9). Second, image filtering techniques working in texture space are used for visual abstraction (e.g., on color maps) [30]. We configured presets for these shading techniques to enable an automated setup for user-defined tasks. For instance, a blueprint rendering style may be automatically selected to represent construction sites in urban planning. Highlighting may also be performed by post-processing the synthesized importance masks with a distance transform in screen space (e.g., for glow effects [36]).

5. RESULTS

We implemented our framework using C++, OpenGL, and GLSL. OpenSceneGraph was used as the rendering engine to handle 3D data sets (e.g., CityGML [16]). The image filters used with the framework were implemented on the GPU with CUDA. All results were rendered in real time on an Intel® Xeon™ 4× 3.06 GHz with 6 GByte RAM and NVidia® GTX 760 GPU with 4 GByte VRAM, and tested with a 23.6" Lenovo® L2461xwa multitouch monitor.

Four interaction interfaces have been implemented to resemble some of the definition types shown in Figure 4: (1) regional definitions via the *pinch-to-zoom metaphor*, (2) a search bar for textual lookup, (3) sliders for thematic data range definition, (4) and direct object selection. In addition, we

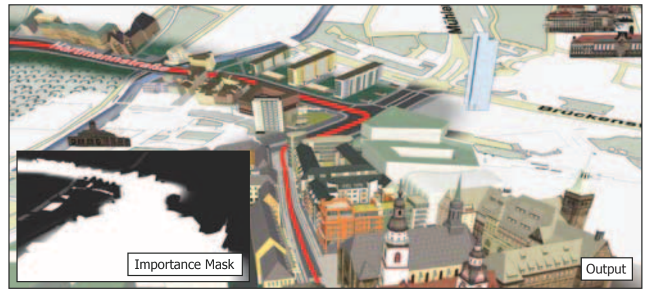

Figure 9: Cartographic shading and landmark highlighting for context regions in a routing scenario [21].

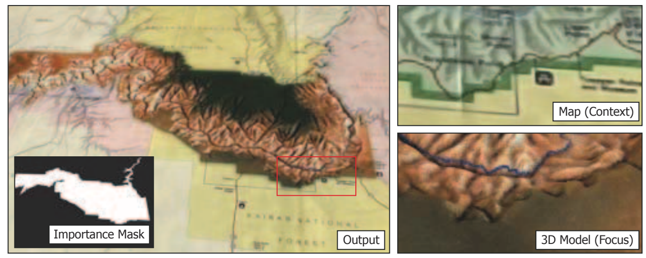

Figure 10: Highlighting of the *Grand Canyon National Park* using a 3D terrain model and a 2D map.

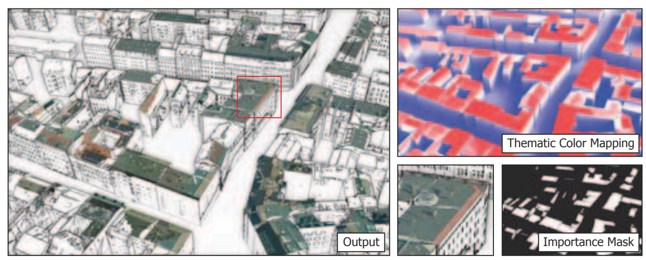

Figure 11: User-defined, thematic selection of "high solar potential data" for focus and context definition.

use distance transforms for route highlighting, and view metrics (e.g., distance) for view-dependent visualization.

Typical user tasks that deal with information exploration require detailed regional information, and only selected information in context regions for navigational purposes. We coupled the *pinch-to-zoom* metaphor with our framework to directly change the graphical representation in regions of interest (Figure 1). The user starts pointing with two fingers and spans – via the zoom metaphor – the range of interest in world space. A pre-selected mode for graphical representation then automatically adjusts the LoA in the focus region. Alternatively, we provide a natural language interface that allows users to directly highlight regions of interest via a search bar with database lookup functionality. Figure 10 exemplifies a semantic lense for the virtual environment of the Grand Canyon that automatically blends a digital terrain model for focus with a projected map for context. We also used this interface to automatically parameterize the semantic depth-of-field (SDoF) effect [17] for object highlighting. Figure 12 shows a result, where the user searched for a specific group of buildings in a local environment.

Another popular task is routing, where the user is interested in information that ease guidance and orientation. Starting from a B-spline route, we render it as a graphical primitive in a texture map, followed by a distance transform. The georeferenced distance map is then used with projective texturing, and is finally thresholded to select the objects close to the route for high-detail shading. Figure 9 exemplifies a result that combines the focus regions along a route with abstract representations of the context regions. This example makes use of multiple mechanisms on graphical core variables in cartographic design [12], such as a degressive perspective in the background to increase screen-space utilization, symbolization concepts to represent land use effectively, and an iconification of landmarks so that their best views always face the viewing direction [31].

We also explored approaches to parameterize a thematic visualization. We implemented a slider interface where the user is able to specify the range of interest for thematic data. Figure 11 demonstrates how this interface was used to highlight areas within the virtual environment of the city of Berlin (Germany) with a high solar potential. Here, difference-of-Gaussians filtering in texture space [30] was used to automatically stylize the context regions.

Figure 12: Semantic depth-of-field and highlighting.

Finally, model variants for urban planning and analysis were made interactively explorable via magic lenses [2]. The user spans a region of interest via direct touch interaction, shifts the lense to a desired location, and selects a model variant via a dropdown menu. The focus area was then exemplary visualized in a blueprint style (Figure 13).

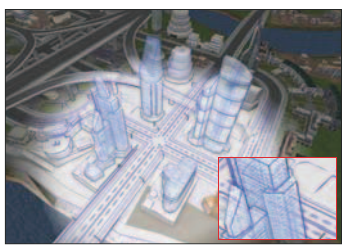

Figure 13: Blueprint stylization for urban planning.

The uses cases demonstrate that image-based rendering techniques are able to effectively map user interaction to focus and context definitions. However, it still requires lots of effort for a developer to integrate new interaction techniques, in particular considering the mapping to GPU uniform buffers, and shader programming. Here, an extensible interface for the rendering backend remains to be explored.

6. CONCLUSIONS AND FUTURE WORK

We present an interaction framework that selects and seamlessly combines the level of abstraction of 3D geovirtual environments according to a user's interest in spatial, semantic, and thematic information. The framework decouples concrete interaction devices and techniques from rendering, and thus provides a generic blueprint for visualization systems that demand for extensible interaction interfaces. We demonstrate its flexibility by the example of typical tasks performed with virtual 3D city and landscape models, such as exploration, navigation, and orientation.

We see multiple directions for future work:

- The paper reports on decoupling the interaction interface from the rendering backend by using a unified parameter space; only a few examples for interaction techniques are presented. In the future, the potentials of a generic framework for user interface developers and designers should be explored to make concrete interaction techniques and devices more easy to deploy. This also includes the exploration of methods to concisely trigger interaction modes.

- Because the presented framework and techniques are designed for generic application, they can also be useful and applied in other visualization domains, such as medical visualization.

- We also plan to explore the application of our framework on mobile devices, i.e., to evaluate the impact of interaction metaphors on a user's task performance when directing a focus+context visualization on limited screen sizes. Once multiple interaction interfaces are designed, it is also mandatory to evaluate their effectiveness. A reasonable approach is presented by Çöltekin et al. [5] who analyzed and evaluated eye movements according to usability metrics.

Acknowledgments

We would like to thank the anonymous reviewers for their valuable comments. This work was funded by the Federal Ministry of Education and Research (BMBF), Germany, within the InnoProfile Transfer research group "4DnD-Vis" (`www.4dndvis.de`).

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